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**LCS Study:
Design Principles of Distributed,
Networked Forces**

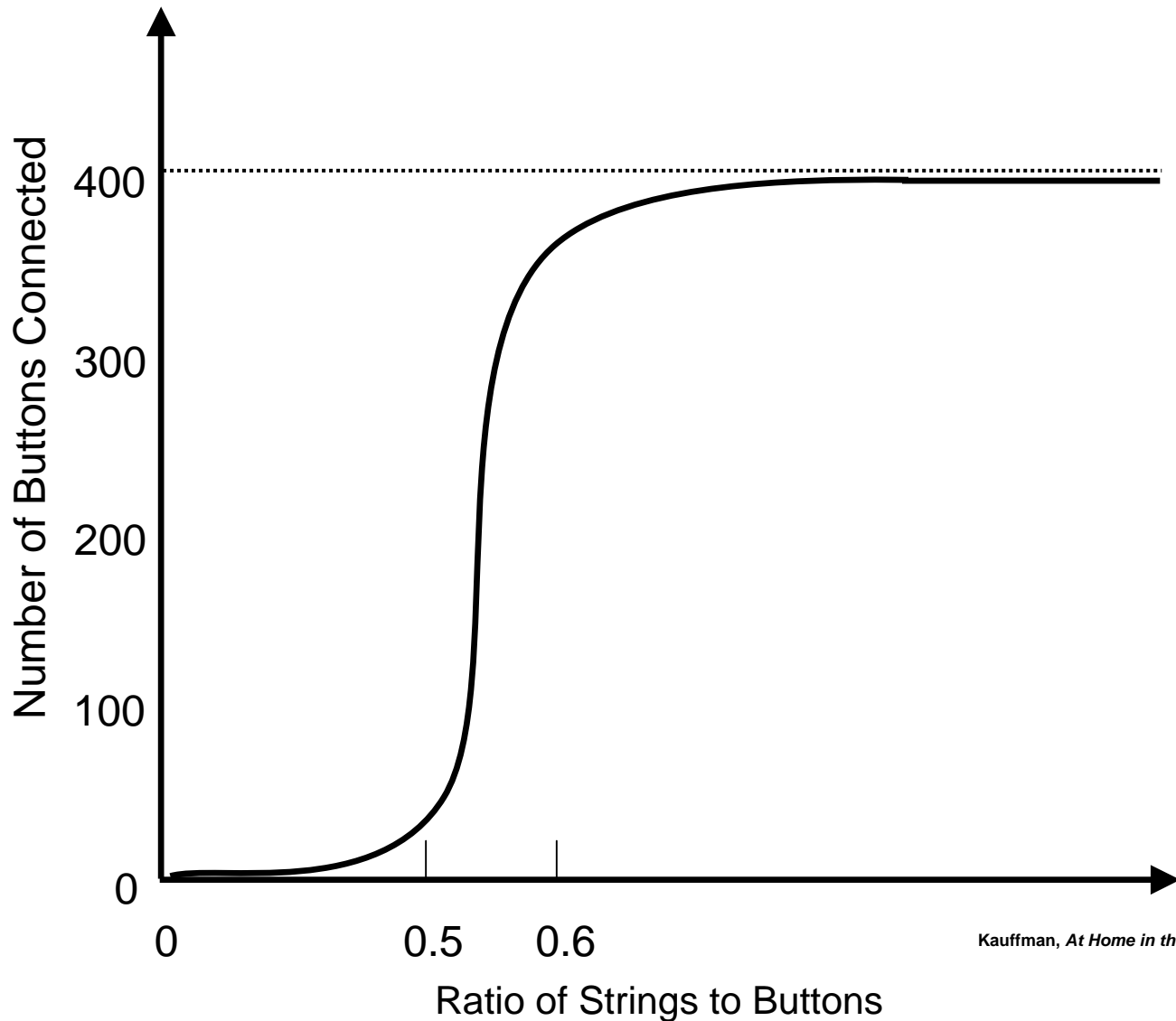
Jeffrey R. Cares

73rd MORSS

Main Points

- “Complex Networks” have exploitable properties
 - e.g.: Information Age commercial/social successes
- These exploitable properties have military relevance
 - e.g.: Sense and Respond Logistics (OSD-FT)
- There are significant distributed, networked force design implications of these properties
- A more satisfying theory of Distributed, Networked Forces (than currently exists for NCW/NCO, etc) is emerging from this research

Buttons and Strings



Kauffman, *At Home in the Universe*, p.57

Network Metric Thumb Rules

Experimentation and Analysis

LCS Study:

Design
Principles of
DNF

Metric	Range	Operational Significance
Number of nodes, n	$n > \sim 100$	Network effects unlikely to occur with $n < 50$
Number of links, l	$l < \sim 2n$	$l \ll 2n$, too brittle $l \gg 2n$, too much overhead
Degree distribution	Skewed	Adaptivity, modularity
Largest hub	< 100 links	Hub appears, recedes by reconnection 5% of links
Average path length	$\log(n)$	Short distances even for large networks (e.g., 10^4 nodes \rightarrow Average path length = ~ 4)
Clustering	Skewed	Hierarchy, organization
Betweenness	Skewed	Cascade control
Path horizon	$\log(n)$	Self-synchronization
Susceptibility/ Robustness	Low (random removal) High (focused removal)	Hubs should be kept obscure until needed, damage abatement/repair schemes
Neutrality Rating	$(0, 1)$	Increased network effects, decreased susceptibility, tipping points
Coefficient of Networked Effects	$(0, 1)$	Network effects PFE/n

Operational Questions

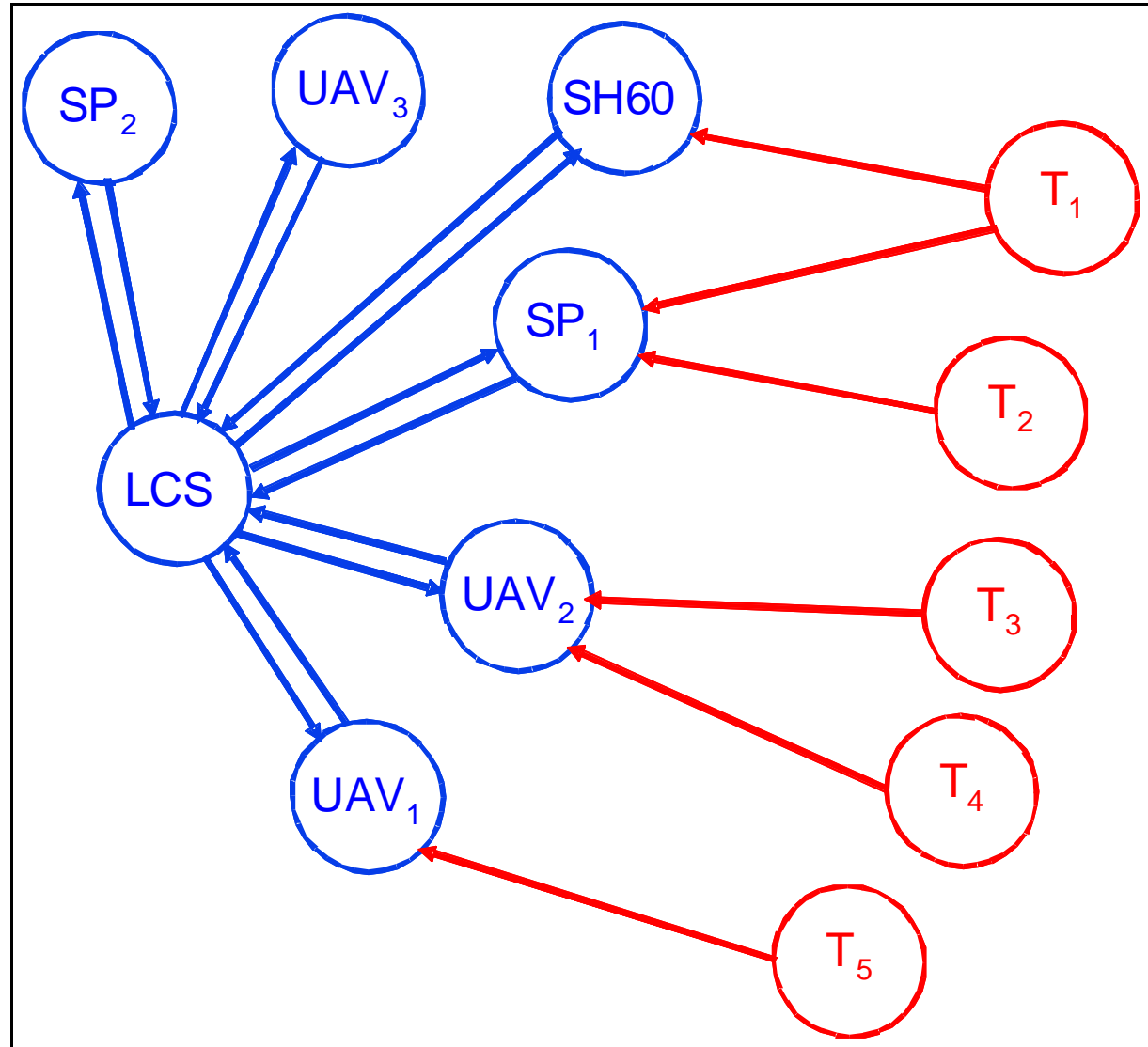
LCS Study:

Design
Principles of
DNF

- *Does the proposed LCS architecture display quantifiable “networked effects”?*
 - Does information flow or arrangement of combat power represent a transformational change in naval operations? What new state configurations emerge that might not have been previously possible?
- *What are the key nodes for information flow or combat capability?*
 - How does this change as multi-mission off board vehicles change roles from search (exploration) to attack (exploitation)? What are the potential “autocatalytic” sets of nodes, if any?
- *How robust is the network in light of the removal of nodes or links (either due to combat or to technical failure)?*
 - This question will help to evaluate how the network may perform under combat conditions. Can new connections be adaptively formed to maintain the integrity of the network?

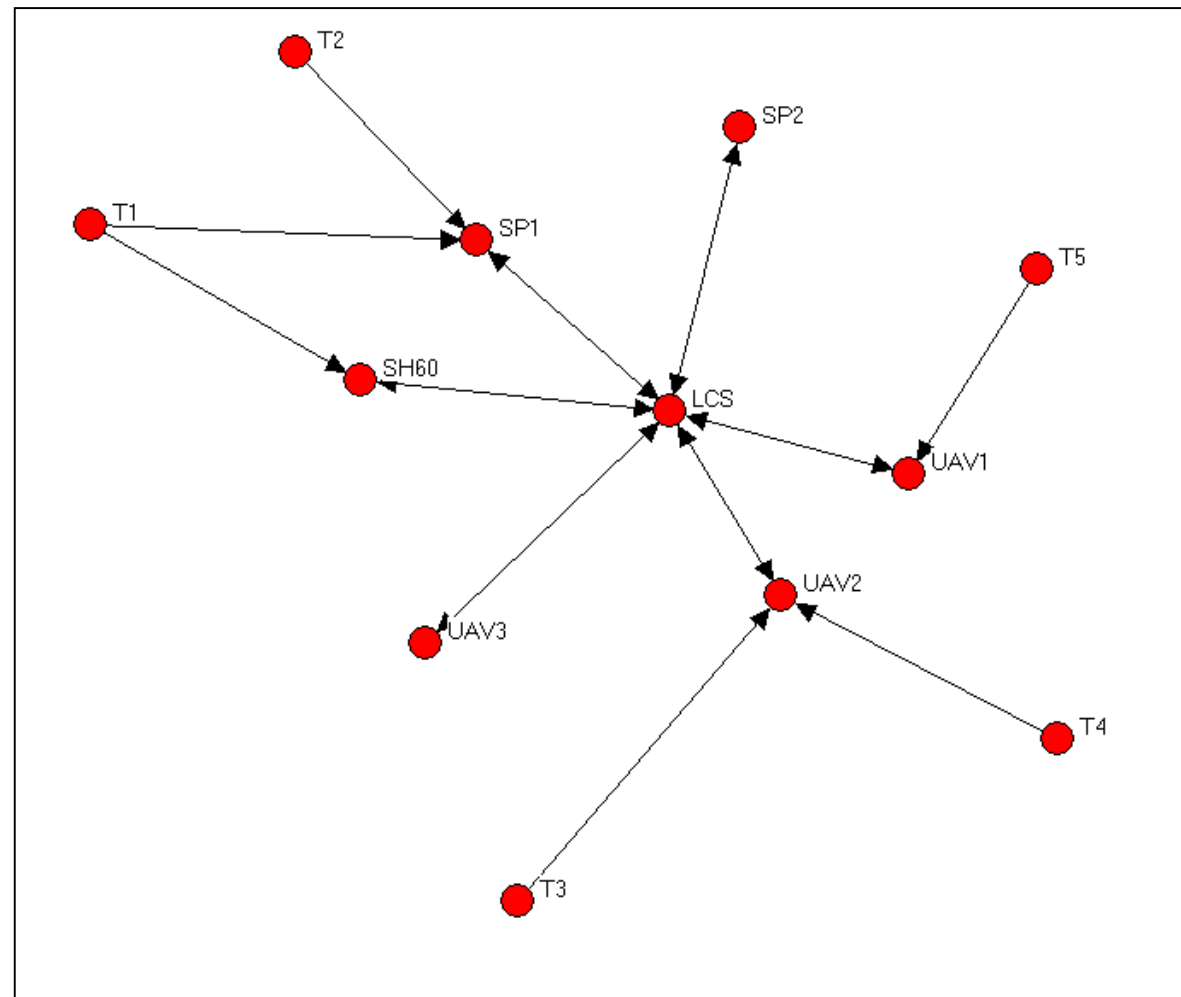
ASUW Case 1

LCS Study:
Design
Principles of
DNF



ASUW Case 1 (Network Diagram)

LCS Study:
Design
Principles of
DNF



ASUW Case 1

(Network Statistics)

LCS Study:

Design
Principles of
DNF

Property	Thumb Rule	Measured	Analysis
Nodes	>50	12	Networked effects difficult
$CNE = PFE/N$	0.2 -0.4	0.204	Networked effects possible
L/N ratio	~ 2	1.50	Very brittle, networked effects difficult, low potential to reconfigure and adapt
Neutrality Rating	$(L-N+1)/N$	0.583	Very little latent network structure, not adaptable
Clustering	Skewed	Uniform, 0	No local cohesion, very brittle structure, tree hierarchy
CPL	1.08	2.08 $10^{2.08} = 120$	Too long: same path length as a 120 node complex network
Degree Dist	Skewed	Skewed	Potential to adapt
Between -ness Dist	Skewed	Skewed	Potential to survive cascading failure

ASUW Case 1

(Network Statistics)

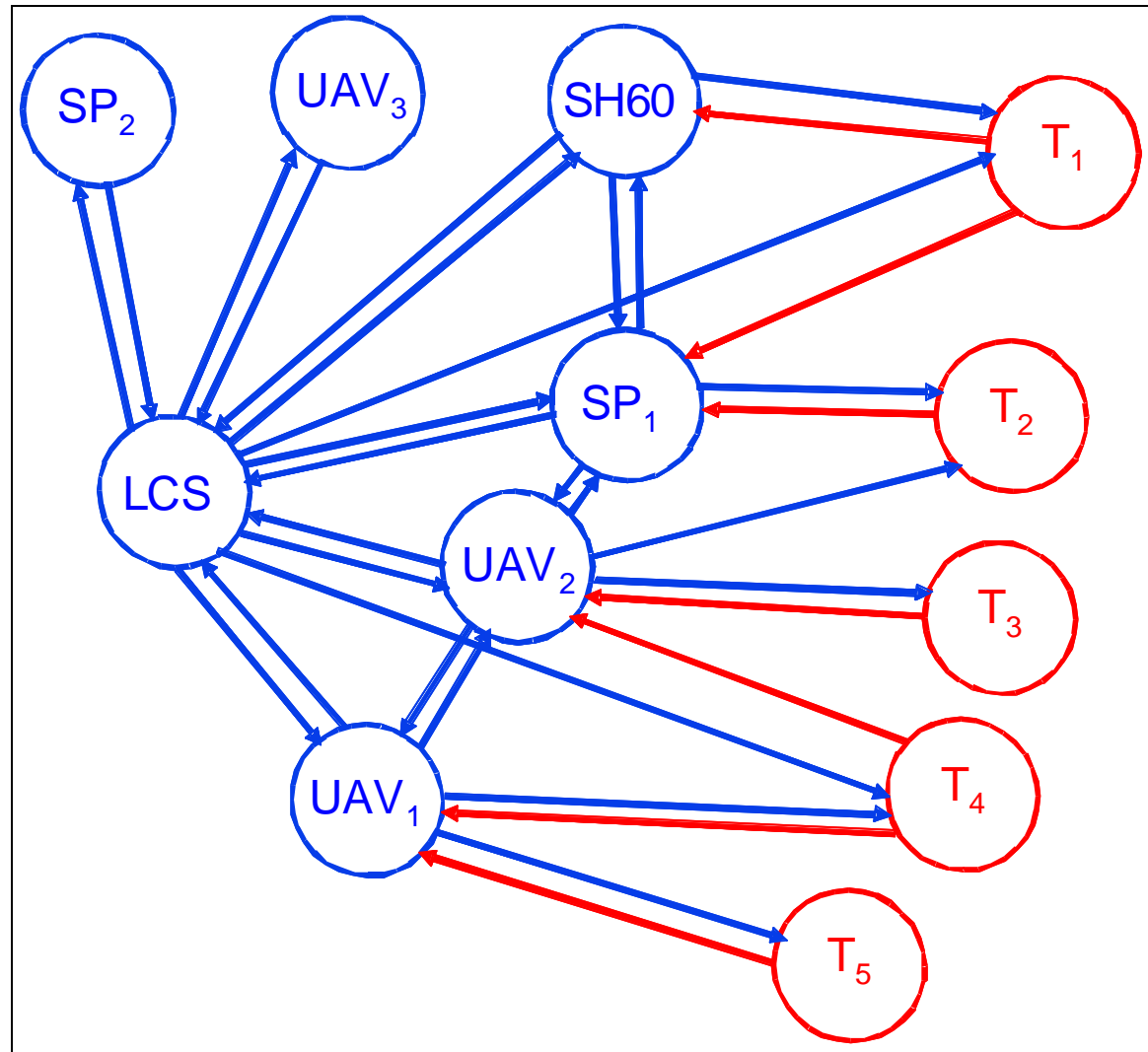
LCS Study:

Design
Principles of
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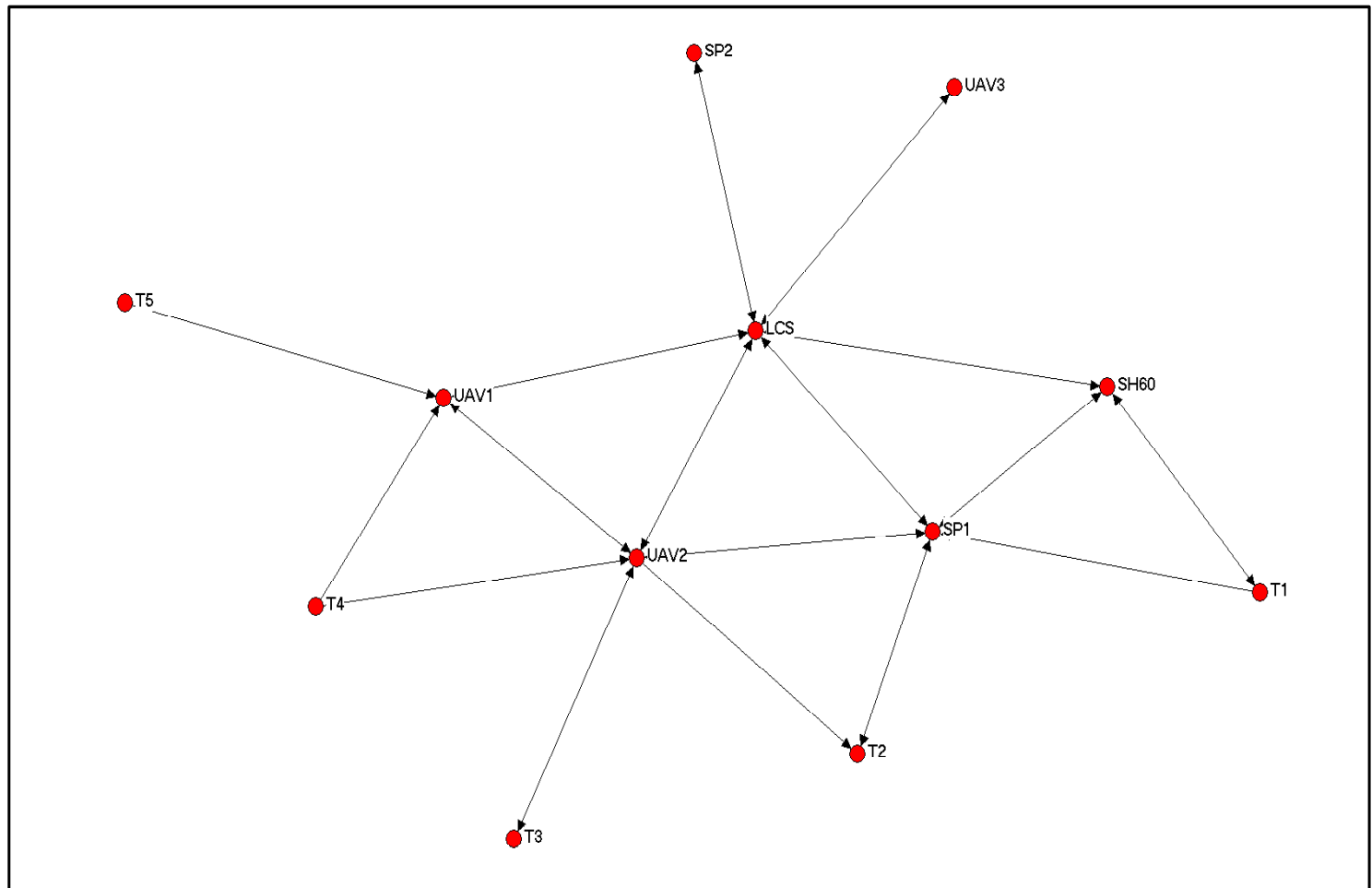
	Betweenness
LCS	54
UAV2	12
SP1	8.5
UAV1	6
SH60	2.5
SP2	0
UAV3	0
T1	0
T2	0
T3	0
T4	0
T5	0

ASUW Case 9

LCS Study:
Design
Principles of
DNF



ASUW Case 9 (Network Diagram)



LCS Study:

Design
Principles of
DNF

ASUW Case 9

(Network Statistics)

LCS Study:

Design
Principles of
DNF

Property	Thumb Rule	Measured	Analysis
Nodes	>50	12	Networked effects difficult
CNE=PFE/N	0.2-0.4	0.283	Networked effects possible
L/N ratio	~2	2.75	Robust, networked effects possible, good potential to reconfigure and adapt
Neutrality Rating	$(L-N+1)/N$	1.83	Significant latent network structure
Clustering	Skewed	$13/47=0.277$	Low overall clustering, but skewed towards T's (as desired)
CPL	$\log(12)=1.08$	2.06 $10^{(2.06)}=115$	Too long: same path length as a 115 node complex network
Degree Dist.	Skewed	Moderately skew	See chart below
Between -ness Dist.	Skewed	Moderately Skew	See chart below

ASUW Case 9

(Network Statistics)

LCS Study:

Design
Principles of
DNF

	Between
	-ness
LCS	46
UAV2	28.7
SP1	19.3
SH60	11.8
UAV1	11.2
UAV3	0
SP2	0
T1-T5	0

Conclusions

- In general, the RFP structures had poor network properties
 - See original report at www.alidade.net
- Method provided new insight into value of different distribution and networking configurations
 - Insights were quantifiable
- More research required to get from “insights” to “useful MOEs”



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Questions?